UCLA Tropical Meteorology and Climate Newsletter, No. 57, 17 April 2003.

Evolution of the 2002-03 El Niño

Michael J. McPhaden
NOAA/Pacific Marine Environmental Laboratory
7600 Sand Point Way NE
Seattle, WA 98115
mcphaden@pmel.noaa.gov

Abstract

Coupled ocean-atmosphere interactions in the tropical Pacific led to the development of an El Niño in 2002-03. The event peaked in the fourth quarter of 2002, and is presently in decline. Conditions indicate an event of moderate intensity and one that is significantly weaker than the strong 1997-98 El Niño. A majority of forecast models predict that the anomalous warm conditions should disappear by boreal summer 2003 (http://iri.columbia.edu/climate/ENSO/currentinfo/SST_table.html). This report briefly summarizes the evolution of the event and highlights some of the important dynamical issues related to its development.

Evolution of the Event

The El Niño/Southern Oscillation (ENSO) cycle is the most prominent year-to-year climate fluctuation affecting the globe. It originates through coupled ocean-atmosphere interactions in the tropical Pacific and extends it influence worldwide though oceanic and atmospheric teleconnections. Warm phases (El Niño) and cold phases (La Niña) recur with a periodicity of roughly 3-7 years. The recent El Niño in 1997-98 was by some measures the strongest of the 20th century; it was followed by cold La Niña conditions from mid-1998 to early 2001.

Precursors to the current El Niño occurred in mid-2001 as sea surface temperatures (SSTs) began to warm near the date line coincident with an increase in westerly wind burst activity in the western Pacific (Fig. 1). These westerlies were associated with active phases of the Madden-Julian Oscillation (MJO) whose origins could be traced to the equatorial Indian Ocean in various atmospheric analyses (Climate Prediction Center, 2002). Episodic westerly wind forcing excited several equatorial intraseasonal Kelvin waves in the latter half of 2001 and early 2002. Strong westerly winds in December 2001 in particular forced a Kelvin wave that depressed the thermocline by 20-30 m and left above normal SSTs in its wake at all longitudes east of the date line in early 2002 (Fig. 1). At the same time, intensified surface winds in the western Pacific produced cooling of the warm pool west of 160°E. These SST changes lead to a weakening of the large-scale zonal SST gradient and to an eastward extension in deep atmospheric convection along the equator towards the date line (Climate Prediction Center, 2002). As a result, NOAA's National Centers for Environmental Prediction (NCEP) issued an El Niño advisory on 10 January 2002 stating that "…warming is being observed over the Tropical Pacific, which could lead to an El Niño by early Spring…"

Interestingly, the oceanic response to the strong December 2001 westerly wind burst was short-lived, and conditions returned to near normal across the basin in April 2002.

Then in May, a strong westerly wind event with extensive zonal fetch led to basin scale warming of over 1°C. A subsequent MJO-related westerly wind burst in June helped to sustain this warming, such that on 11 July 2002 NCEP declared "…El Niño is back…"

The latter half of 2002 witnessed the amplification of both oceanic and atmospheric anomalies associated with the El Niño. Episodic westerly wind forcing in the western Pacific continued to excite equatorial Kelvin waves that depressed the thermocline in the eastern Pacific. These winds also excited westward propagating upwelling Rossby waves that elevated the thermocline west of the date line (Fig. 2). By November 2002, the thermocline was 50 m deeper in the east, 30 m shallower in the west, and nearly flat between 140°W and 140°E along the equator (Fig. 3). Westerly winds also drove intense eastward current along the equator, advecting the western Pacific warm pool into the central Pacific (Lagerloef et al, 2003). As SST warmed in the central Pacific, anomalous deep convection and cloudiness associated with the ascending branch of the Walker Circulation shifted eastward and became anchored near the date line.

Despite a strong westerly wind burst in the western Pacific in November-December 2002, the El Niño has been in decline since then as measured by the intensity of SST anomalies, the structure of thermocline depth anomalies along the equator, and zonal winds. A gradually shoaling thermocline has extended eastward along the equator beginning in late 2002, qualitatively consistent with delayed oscillator physics (Battisti, 1988; Schopf and Suarez, 1988) in which upwelling Rossby waves reflect into upwelling equatorial Kelvin waves at the western boundary (Fig. 2). However, thermocline shoaling along the equator in early 2003 is also in part related to upwelling Kelvin waves forced by anomalous easterly winds in the far western Pacific, as observed during the demise of previous El Niños (Weisberg and Wang, 1997; McPhaden and Yu, 1999).

Heat content in the equatorial band is also diminishing, consistent with expectations from recharge oscillator theory for the final stages of an El Niño event (Jin, 1997). The heat content anomaly averaged across the basin has been trending towards negative values since October 2002 and became negative in February 2003 (Fig. 4). Heat content along the equator leads equatorial SST indices by several months (Meinen and McPhaden, 2000), so based on heat content trends we would expect the El Niño to be over by boreal summer.

Comparison with the 1997-98 El Niño

The evolution of the 2002-03 El Niño is similar in some respects to what occurred during the 1997-98 El Niño. The onset of that event was characterized by several westerly wind events in the western Pacific, the excitation of equatorial intraseasonal Kelvin waves, SST warming east of the date line, SST cooling west of 160°E, and a weakening of the thermocline slope along the equator. The westerly wind bursts, dynamical ocean responses, and SST changes in 1997-98 were generally much stronger than in 2002-03 however (see McPhaden, 1999). Also, the 1997-98 El Niño took hold 2-3 months earlier in the calendar year and developed more rapidly.

According to the recharge oscillator theory for El Niño, a build up of excess heat content along the equator is a prerequisite for the occurrence of El Niño. The magnitude of the subsequent SST anomalies usually scales in proportion to the magnitude of the heat content accumulation (Meinen and McPhaden, 2000). The heat content build up prior to the 2002-03 El Niño was about half that prior to 1997-98, and comparable to that prior to the 1986-87 and 1991-92 El Niños (Fig. 5). Based on this heat content precursor, one would have expected maximum SST anomalies for the current event to be significantly smaller than in 1997-98 and similar to those in 1986-87 and 1991-92.

The largest SST anomalies during the current event were concentrated in the central equatorial Pacific, with relatively weak and short-lived warming in the eastern Pacific and along the west coasts of the Americas. The pattern of anomalies resembled that observed during the weak 1994-95 El Niño but contrasted with that of the 1997-98 El Niño and most previous events. Typically, largest SST anomalies are concentrated further east along the equator and the coastal warmings are more pronounced. What accounts for the differences in SST anomaly patterns between El Niños is at present not well understood.

Summary and Discussion

Available observations underscore the role played by both episodic atmospheric forcing (largely associated with the MJO) and large-scale low frequency ocean-atmosphere dynamics in the genesis of ENSO warm events. It's clear for example that the onset of the 2002-03 El Niño was linked to MJO-related westerly events, particularly the one in May 2002. In contrast, episodic westerlies were present in mid-to-late 2001 in the western Pacific but no El Niño developed then. The difference in the effect of these wind events may relate to the level of preconditioning by large-scale dynamics (e.g. heat content build up along the equator) in 2001 vs 2002 and/or to the relative strength of the westerly events. In either case, these observations can be interpreted as consistent with the hypothesis that ENSO is a weakly damped or stable oscillator requiring atmospheric noise to initiate warm events (Moore and Kleeman, 1999; Kessler, 2002).

Interaction of ENSO time scale variability with lower frequency phenomena may also be important for understanding the details of what transpired during the 2002-03 El Niño as well as during the prolonged cold period (mid-1998 to 2001) leading up to it. Changes in large-scale background conditions can affect the character of ENSO (Fedorov and Philander, 2000) and there is evidence to suggest that the Pacific Decadal Oscillation (PDO) may have switched sign from a high phase (warm tropics and coastal Americas) to a low phase (cold tropics and coastal Americas) in the late 1990s (Chavez et al, 2003). It's plausible that a cooler background state in the tropical Pacific might favor weaker El Niños and stronger La Niñas on average relative to the previous 25 years of PDO warm phase conditions. However, it is not clear at present whether the PDO is a cause or a result of decadal modulations in ENSO variability, so precisely how ENSO and the PDO interact with one another remains an open question.

Finally, as one measure of progress in ENSO forecasting, several models in early 2002 predicted that the year would be unusually warm (Kerr, 2002). However, there was considerable spread in ENSO forecasts during early 2002, with some predicting near neutral or cold conditions in the tropical Pacific over the next 2-3 seasons (Kirtman, 2002). By June after warm conditions were established, most models predicted continuation of warm NINO3.4 SST anomalies into early 2003, but with weaker amplitudes than were later observed. Model biases and/or inadequate specification of initial conditions may have contributed to these forecast uncertainties. In addition, the occurrence of energetic intraseasonal oscillations were probably also a significant limitation to ENSO forecast skill (e.g. Eckart and Latif, 1997; Kirtman and Schopf, 1998). Most atmospheric circulation models used in dynamical forecasting schemes do not simulate intraseasonal oscillations well, if at all. Statistical ENSO forecast models, trained on seasonally averaged conditions over many ENSO cycles, are not particularly sensitive to short-lived episodic atmospheric fluctuations. These fluctuations, which represent unpredictable noise on seasonal time scales, appear to have had a significant influence on the timing and the amplitude of the 2002-03 El Niño.

References

Battisti, D. S., 1988: Dynamics and thermodynamics of a warming event in a coupled atmosphere-ocean model, J. Atmos. Sci., 45, 2889–2919.

Chavez, F. P, J. Ryan, S. E. Lluch-Cota,and M. Ñiquen, 2003: From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. Science, 299, 217-221.

Climate Prediction Center, 2002: Climate Diagnostics Bulletin, Near Real-time Analyses, January 2002. U.S. Dept. of Comm., Washington, D.C, , 89 pp..

Eckert C., and M. Latif, 1997: Predictability of a stochastically forced hybrid coupled model of El Niño. J. Clim.,10, 1488–1504.

Fedorov, A.V. and S.G. Philander, 2000: Is El Niño Changing? Science, 288, 1997-2001.

Jin, F.F., 1997: An equatorial recharge paradigm for ENSO. Part I: Conceptual model. J. Atmos. Sci., 54, 811-829.

Kerr, R., 2002: Signs of success in forecasting El Niño. Science, 97, 497-498.

Kessler. W. S., 2002: Is ENSO a cycle or a series of events?. Geophys.Res.Lett., 29, 2125-2128.

Kirtman, B. P., and P. S. Schopf, 1998: Decadal variability in ENSO predictability and prediction. J. Climate, 11, 2804–2822.

Kirtman, B. (Editor), 2002: Experimental Long-lead Forecast Bulletin, March 2002. Center for Ocean-Land-Atmosphere Studies, Calverton, MD, Vol. 11, No. 5, 57pp. (available at http://www.iges.org/ellfb)

Lagerloef, G. S. E., R. B. Lukas, F. Bonjean, J. Gunn, G. T. Mitchum, M. Bourassa, and A. J. Busalacchi, 2003: El Niño Tropical Pacific surface current and temperature evolution in 2002 and outlook for early 2003. Geophys. Res. Lett., in press.

McPhaden, M.J., 1999: Genesis and evolution of the 1997-98 El Niño. Science, 283, 950-954.

McPhaden, M.J., 2003: Tropical Pacific Ocean heat content variations and ENSO persistence barriers. Geophys. Res. Lett., in press.

McPhaden, M.J. and X. Yu, 1999: Equatorial waves and the 1997-98 El Niño. Geophys. Res. Lett., 26, 2961-2964.

Moore, A. M., and R. Kleeman, 1999: Stochastic forcing of ENSO by the intraseasonal oscillation. J. Clim., 12, 1199-1220.

Meinen, C.S. and M.J. McPhaden, 2000: Observations of warm water volume changes in the equatorial Pacific and their relationship to El Niño and La Niña. J. Clim., 13, 3551-3559.

Schopf, P. S., and M. J. Suarez, 1988: Vacillations in a coupled ocean-atmosphere model, J. Atmos. Sci., 45, 549–566.

Weisberg, R. H., and C. Wang, 1997: A western Pacific oscillator paradigm for the El Niño-Southern Oscillation. Geophys. Res. Lett., 24, 779-782.

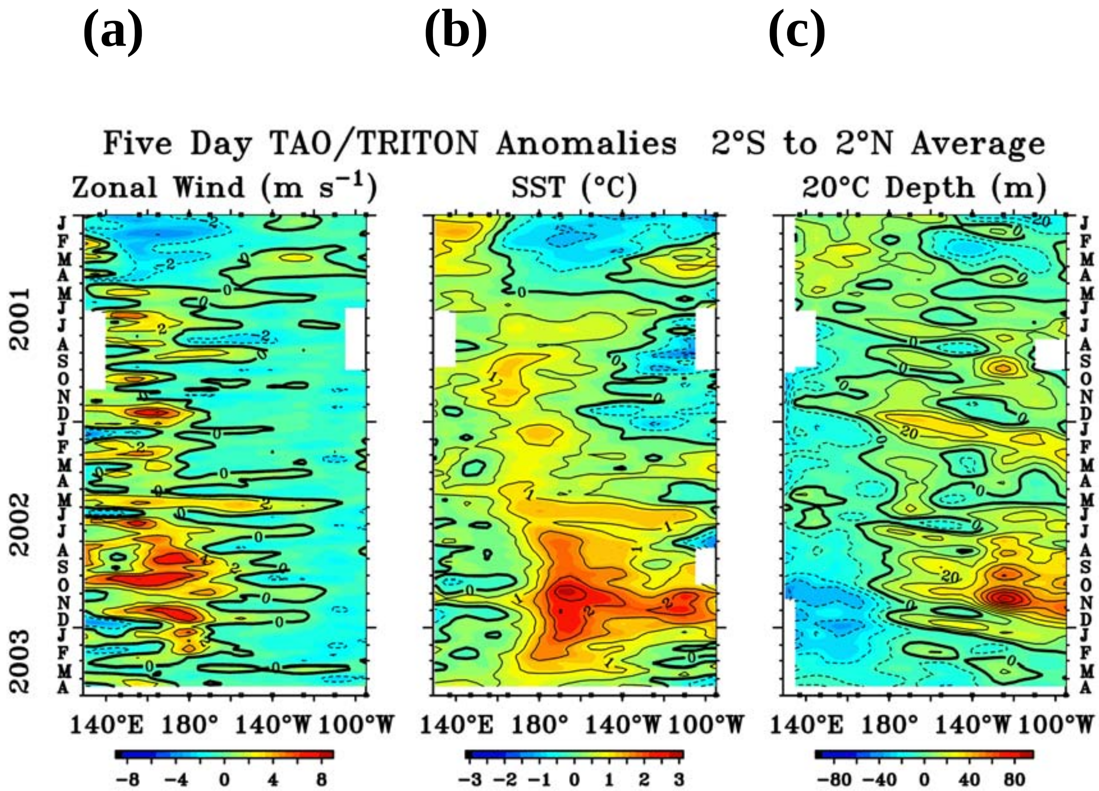

Figure 1. Five-day analyses of (a) zonal wind, (b) SST, and (c) 20°C depth anomalies averaged 2°N-2°S based on TAO/TRITON moored time series data.

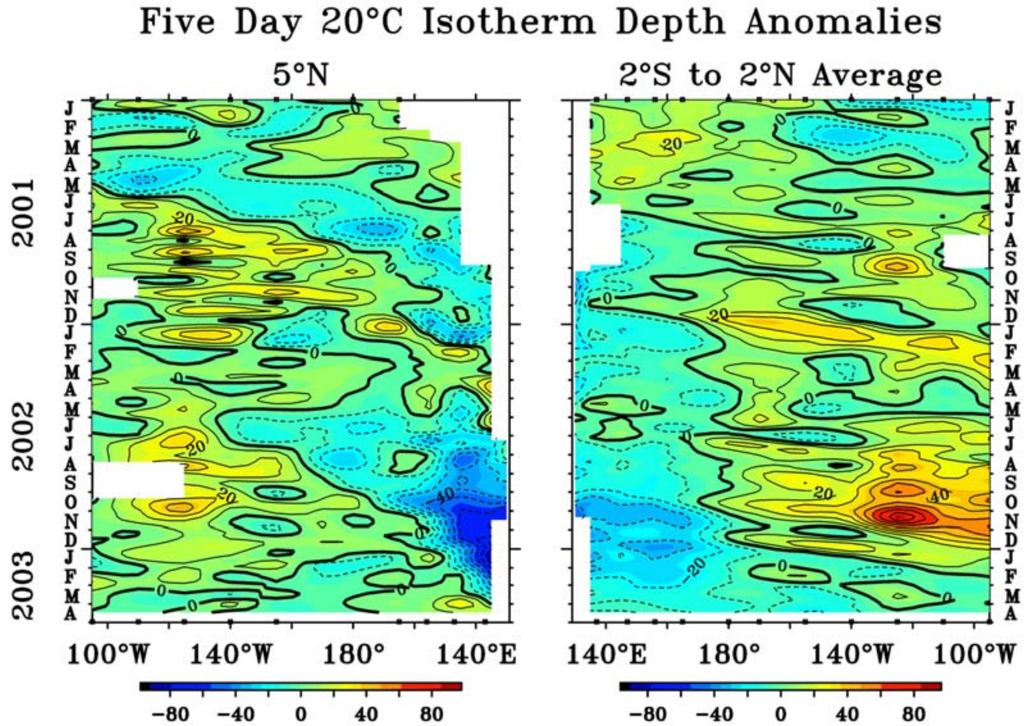

Figure 2. Five day analyses of 20°C depth isotherm anomalies along 5°N (left) and averaged between 2°N-2°S. The longitudinal axis has been reversed on the left panel to show connectivity of westward propagating anomalies along 5°N with eastward propagating anomalies along the equator.

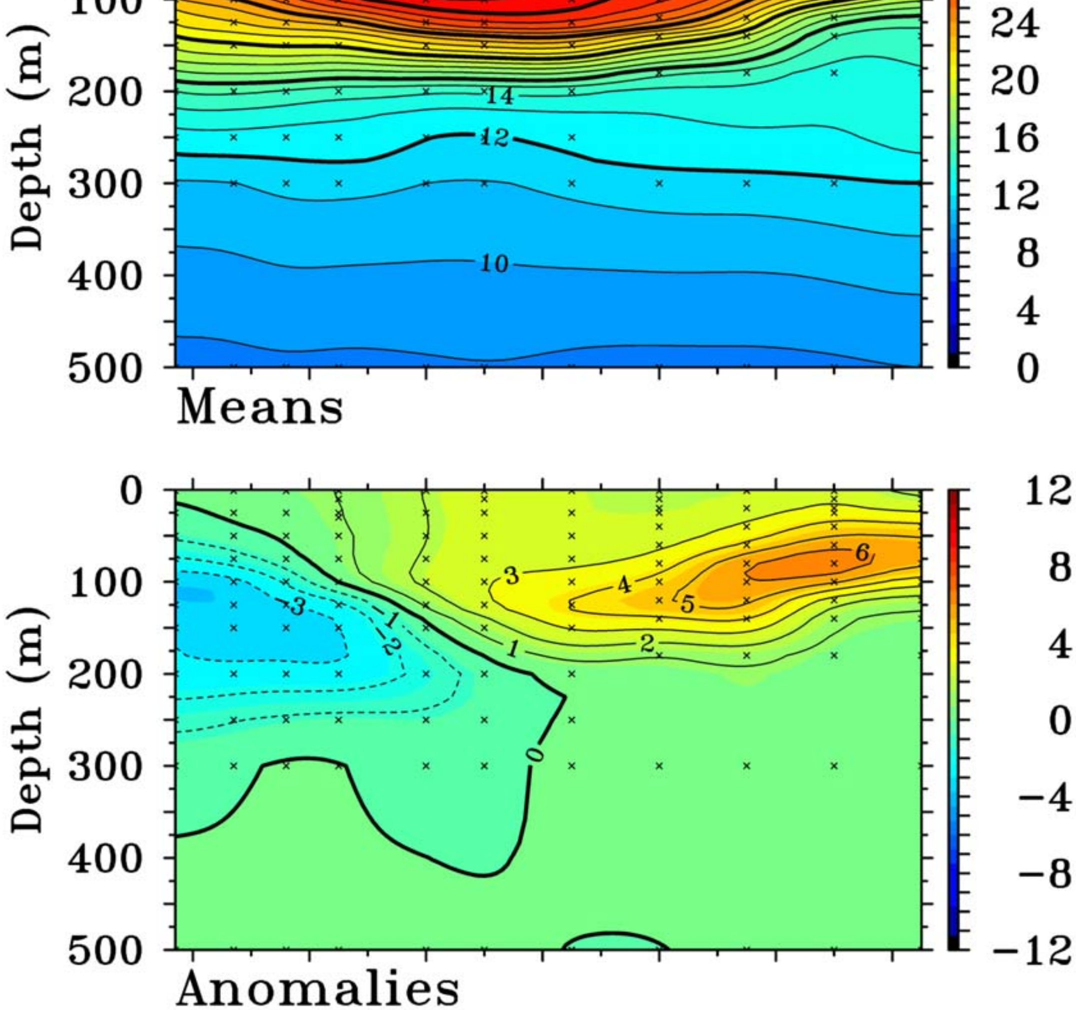

Figure 3. Zonal section of November 2002 temperatures (top) and temperature anomalies (bottom) along the equator averaged between 2°N and 2°S based on TAO/TRITON time series.

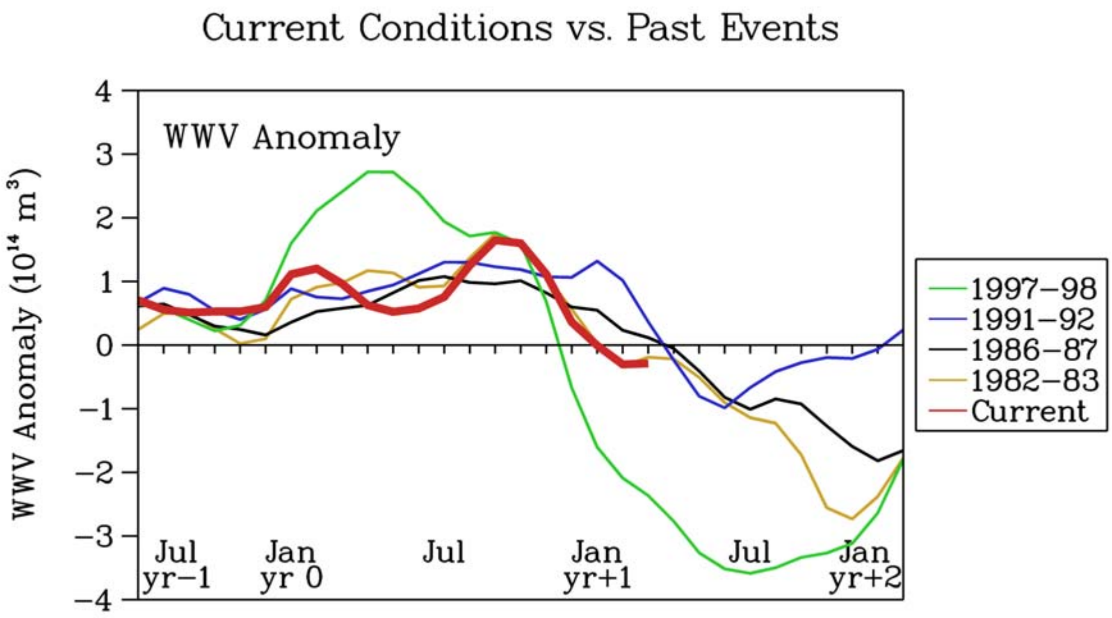

Figure 4. Warm water volume anomalies (5°N-5°S, 80°W-120°E above the 20°C isotherm) for El Niños since 1980. Time axis starts in July the year before the warm event (Jul, Yr-1) and continues through January the year after the end of the event (Jan, Yr+2). The time series for the 2002-03 El Niño (Current) starts in July 2001 and ends in March 2003. (after McPhaden, 2003)

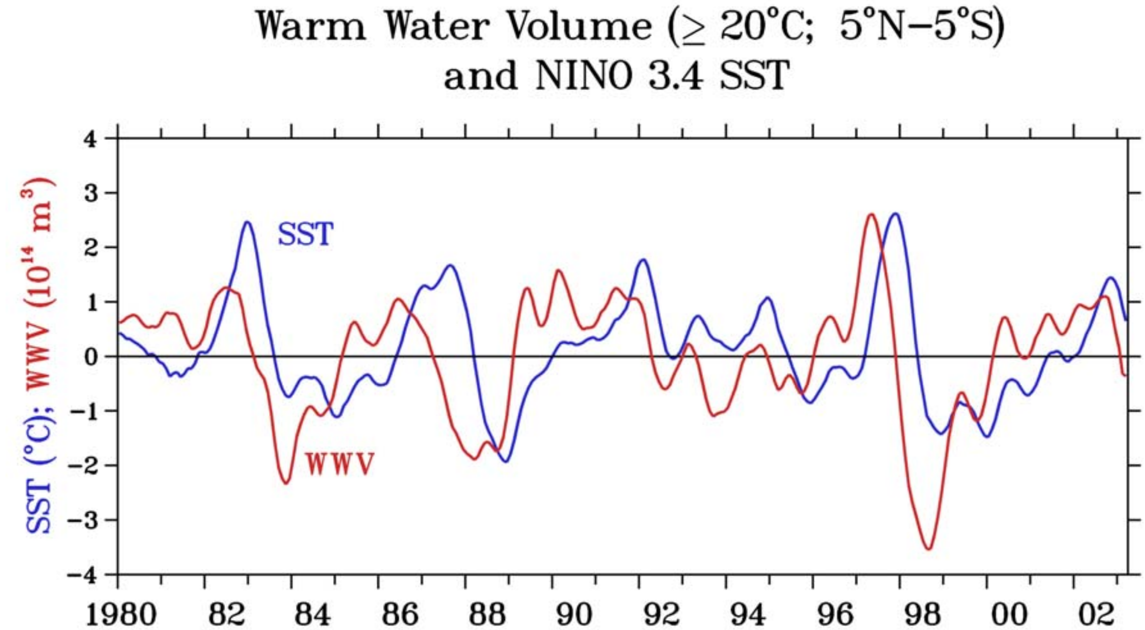

Figure 5. Monthly anomalies of warm water volume (5°N-5°S, 80°W-120°E above the 20°C isotherm) and NINO3.4 SST (5°N-5°S, 120°W-170°W) from January 1980 to March 2003. Time series have been smoothed with a 5-month running mean filter for display (after McPhaden, 2003)